Patent Application
Docket No. TI- 30650

CERTIFICATE OF MAILING BY EXPRESS MAIL

"EXPRESS MAIL" Mailing Label No. EJ042687421US
Date of Deposit: July 7, 2000
I hereby certify that this paper or fee is being deposited with the U.S. Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Box Patent Application, Washington, D.C. 20231.

Type or Print Name: Joy L. Mowery

Signature:

DYNAMIC SLAVE SELECTION IN FREQUENCY HOPPING WIRELESS COMMUNICATIONS

R.N. 2/12/04

This application claims the priority under 35 U.S.C. 119(e)(1) of copending U.S. provisional application number 60/185,93~~6~~7, filed on February 29, 2000.

FIELD OF THE INVENTION

The invention relates generally to wireless communications and, more particularly, to frequency hopping wireless communications.

BACKGROUND OF THE INVENTION

Present telecommunication system technology includes a wide variety of wireless networking systems associated with both voice and data communications. An overview of several of these wireless networking systems is presented by Amitava Dutta-Roy, *Communications Networks for Homes*, IEEE Spectrum, pg. 26, Dec. 1999. Therein, Dutta-Roy discusses several communication protocols in the 2.4 GHz band, including IEEE 802.11 direct-sequence spread spectrum (DSSS) and frequency-hopping (FHSS) protocols. A disadvantage of these protocols is the high overhead associated with their implementation. A less complex wireless protocol known as Shared Wireless Access Protocol (SWAP) also operates in the 2.4 GHz band. This protocol has been developed by the HomeRF Working Group and is supported by North American communications companies. The SWAP protocol uses frequency-hopping spread spectrum technology to produce a data rate of 1 Mb/sec. Another less complex protocol is named Bluetooth after a 10th century Scandinavian king who united several Danish kingdoms. This protocol also operates in the 2.4 GHz band and advantageously offers short-range wireless communication between Bluetooth devices without the need for a central network.

The Bluetooth protocol provides a 1 Mb/sec data rate with low energy consumption for battery powered devices operating in the 2.4 GHz ISM (industrial, scientific, medical)

band. The current Bluetooth protocol provides a 10-meter range and a maximum asymmetric data transfer rate of 723 kb/sec. The protocol supports a maximum of three voice channels for synchronous, CVSD-encoded transmission at 64 kb/sec. The Bluetooth protocol treats all radios as peer units except for a unique 48-bit address. At the start of any connection, the initiating unit is a temporary master. This temporary assignment, however, may change after initial communications are established. Each master may have active connections of up to seven slaves. Such a connection between a master and one or more slaves forms a "piconet." Link management allows communication between piconets, thereby forming "scatternets." Typical Bluetooth master devices include cordless phone base stations, local area network (LAN) access points, laptop computers, or bridges to other networks. Bluetooth slave devices may include cordless handsets, cell phones, headsets, personal digital assistants, digital cameras, or computer peripherals such as printers, scanners, fax machines and other devices.

The Bluetooth protocol uses time-division duplex (TDD) to support bi-directional communication. Frequency hopping permits operation in noisy environments and permits multiple piconets to exist in close proximity. The frequency hopping scheme permits up to 1600 hops per second over 79 1-MHZ channels or the entire 2.4 GHz ISM spectrum. Various error correcting schemes permit data packet protection by 1/3 and 2/3 rate forward

error correction. Further, Bluetooth uses retransmission of packets for guaranteed reliability. These schemes help correct data errors, but at the expense of throughput.

The Bluetooth protocol is specified in detail in Specification of the Bluetooth System, Version 1.0A, July 26, 1999, which is incorporated herein by reference.

In frequency hopping wireless communications systems such as the Bluetooth system, there can be considerable variation in the quality of the channel at various frequencies due, for example, to different fading and interference conditions at each frequency. Transmission on frequencies with low $E_b/(N_O+I_O)$ (signal-to-noise + interference ratio) usually results in many bit errors, which leads either to poor voice quality in voice transmissions or lost data packets in data transmissions.

It is therefore desirable to avoid transmission on frequencies with a low signal-to-noise plus interference ratio.

The present invention monitors the quality of various frequency channels between first and second frequency hopping wireless communication devices. Based on the monitored quality information, communications between the first and second devices can be scheduled with respect to a predetermined frequency hopping pattern such that the communications are advantageously transmitted on selected frequencies that are more likely than others to provide acceptable communication performance.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 diagrammatically illustrates pertinent portions of exemplary embodiments of a master device according to the invention.

FIGURE 2 diagrammatically illustrates exemplary ACL communications between the master device of FIGURE 1 and a pair of conventional slave devices.

FIGURE 3 diagrammatically illustrates exemplary ACL communications between a master device and two slave devices according to the invention.

FIGURE 4 diagrammatically illustrates pertinent portions of exemplary embodiments of the master device of FIGURE 3.

FIGURE 5 diagrammatically illustrates pertinent portions of an exemplary embodiment of the slave devices of FIGURE 3.

FIGURE 6 diagrammatically illustrates exemplary SCO link communications between the master device of FIGURE 1 and a further slave device according to the invention.

FIGURE 7 diagrammatically illustrates pertinent portions of an exemplary embodiment of the slave device of FIGURE 6.

FIGURE 8 diagrammatically illustrates exemplary SCO link communications between the master device of FIGURE 4 and a further slave device according to the invention.

FIGURE 9 diagrammatically illustrates pertinent portions of an exemplary embodiment of the slave device of FIGURE 8.

FIGURE 10 diagrammatically illustrates exemplary SCO link communications between the master device of FIGURE 1 and a plurality of the slave devices of FIGURE 7.

FIGURE 11 diagrammatically illustrates exemplary SCO link communications between the master device of FIGURE 4 and a plurality of the slave devices of FIGURE 9.

FIGURE 12 illustrates exemplary operations which can be performed by the master device embodiments of FIGURES 1 and 4.

FIGURE 13 diagrammatically illustrates a modified slave frequency hopping pattern utilized by the present invention.

FIGURE 14 diagrammatically illustrates pertinent portions of exemplary embodiments of a master device that supports the modified slave frequency hopping pattern of FIGURE 13.

FIGURE 15 diagrammatically illustrates pertinent portions of an exemplary embodiment of a slave device which implements the modified slave frequency hopping pattern illustrated in FIGURE 13.

FIGURE 16 diagrammatically illustrates exemplary SCO link communications between the master device of FIGURE 14 and the slave device of FIGURE 15.

FIGURE 17 illustrates exemplary operations which can be performed by the master device of FIGURE 14.

FIGURES 18-20 illustrate exemplary simulation results obtained according to the present invention.

DETAILED DESCRIPTION

FIGURE 1 diagrammatically illustrates pertinent portions of exemplary embodiments of a master device according to the invention, for example a Bluetooth master device such as described above. The device of FIGURE 1 includes a packet processor 11 coupled for communications with a communications application 13 and a wireless communications interface 12. The communications application 13 provides communication information to the packet processor 11, which can use well-known conventional techniques to assemble packets suitable for communication of the information received from the communications application 13. The assembled packets are then forwarded at 21 to a scheduler 16 which produces therefrom a modified packet flow at 22. This modified packet flow is input to the wireless communications interface 12, which can use well-known conventional wireless communication techniques to transmit the received packets, via one or more antennas at 15, across a wireless communication link 18 (for example a Bluetooth radio link) to one or more slave devices. Similarly, the wireless communications interface 12 can receive packets from the slave device(s) via the wireless communication link 18, again using well-known conventional techniques, and can forward the received packets to the packet processor 13. The packet processor 13 can use conventional techniques to disassemble the received packets

and forward to the communications application 13 the information contained in the received packets.

The scheduler 16 is operable in response to frequency channel quality information at 19, frequency hopping pattern information at 20, and information received at 17 from the communications application 13 for scheduling master-to-slave transmissions so as to avoid frequencies which are known to provide poor communication performance and utilize instead frequencies which are known to provide adequate communication performance. In some embodiments, even some frequencies which provide adequate communication performance are avoided in favor of frequencies which provide even better communication performance, in order to enhance the quality-of-service for selected communications.

The scheduler 16 includes an input 19 for receiving conventionally available information indicative of the quality of the channel to each slave for all available transmit frequencies, so that the scheduler will know the best frequencies available for transmission to each slave. The scheduler 16 also has an input 20 for receiving conventionally available information indicative of the normal frequency hopping pattern utilized by the wireless communications interface 12. The scheduler 16 also receives at 21 from the packet processor 11 the normal flow of master-to-slave (MS) packets conventionally produced by the packet processor 11 from the communication information provided by communications application

13. Based on the frequency hopping pattern information at 20 and the frequency channel quality information at 19, the scheduler 16 outputs at 22 to the wireless communications interface 12 a modified master-to-slave packet flow that avoids poor frequencies and utilizes stronger frequencies. The scheduler can also receive at 17 information indicative of the quality-of-service required for communication to a given slave, and/or the amount of information that needs to be transmitted to a given slave. The quality-of-service information can be used by the scheduler to select a best frequency from among a plurality of adequate frequencies for transmission to a given slave. If the information at 17 indicates that a large amount of information needs to be transmitted to a given slave, the scheduler may increase the size of that slave's packet(s) in the modified packet flow 22.

The frequency channel quality information at 19 can, in some Bluetooth embodiments, be based upon the value of the correlation with the sync word for packets received by the master. If the sync word correlation value is high, then the $E_b/(N_O+I_O)$ will usually be high. Another exemplary indicator of frequency channel quality is the CRC (cyclic redundancy code) of received data packets. This CRC can be checked to determine whether the packet was received correctly, which would indicate whether or not the channel is acceptable. Another example of frequency channel quality information is the conventional Bluetooth acknowledgment (ACK) or negative acknowledgment (NAK) received from the

slave device(s) in response to a previous master-to-slave transmission, the negative acknowledgment indicating a potential problem with the quality of that frequency channel. Additionally, an estimate of the coherence bandwidth can be made to determine whether nearby frequencies will have fading characteristics that are similar to a given frequency, thus providing additional frequency channel quality information.

As an example of the operation of scheduler 16, assume that the master device of FIGURE 1 has data packets for transmission to first and second slave devices. If the frequency specified by the normal frequency hopping pattern for the master device's next transmission to the first slave device is, for example, in a deep fade for the channel to the first slave device, but the channel to the second slave device on that frequency is very good, then the scheduler 16 would choose that frequency for transmission to the second slave device, because transmission of a packet to the second slave device on that frequency is more likely to be successful than transmission of a packet to the first slave device on that frequency.

As another example, other factors such as the amount of information that needs to be transmitted to a given slave device, the latency requirements (e.g., a data file can tolerate a longer total transmission delay than real-time applications such as voice), and the mean channel attenuation can also be taken in account. For example, if the first slave device is

much closer to the master device than is the second slave device, so that the mean channel attenuation to the first slave device is smaller than to the second slave device, then the scheduler 16 may choose to transmit to the second slave device on the frequency specified by the frequency hopping pattern for transmission to the first slave device, even when the channel to the first slave device is better for that frequency. Because the mean channel attenuation to the first slave device is smaller, transmission to the first slave device on another upcoming frequency, which may provide inferior performance relative to the frequency specified by the frequency hopping pattern for transmission to the first slave device, can still be expected to be adequate for the transmission to the first slave device.

In a further example, if the channel quality for the frequency specified by the normal frequency hopping pattern for transmission to a given slave is very good, and/or if the master device has a large amount of information for transmission to that slave, then the scheduler 16 may choose to send a larger packet to that slave to take advantage of the good channel quality. Also, if it is determined that an upcoming frequency in the normal frequency hopping pattern provides a poor channel to all of the slave devices, for example due to a temporary fading condition, then the scheduler 16 may choose to avoid that upcoming frequency by transmitting a larger packet to one of the slaves before the poor frequency is reached. In systems such as the Bluetooth system, the transmission frequency does not

change in the middle of the packet, so the identified poor frequency can be avoided (i.e., bypassed) until its quality improves.

In another exemplary embodiment, both the master-to-slave (MS) transmission frequency and the slave-to-master (SM) transmission frequency specified by the normal frequency hopping pattern can be considered by the scheduler 16. In such embodiments, the scheduler evaluates the channel quality of both the master-to-slave frequency and the corresponding slave-to-master frequency for a plurality of possible master-to-slave/slave-to-master frequency pairs, and selects a pair that provides acceptable channel quality. The aforementioned technique of increasing the size of the master-to-slave packet can also be used to bypass poor frequencies until a master-to-slave/slave-to-master frequency pair of acceptable quality is reached.

FIGURE 2 diagrammatically illustrates exemplary Bluetooth ACL (Asynchronous Connection-Less) communication of packets between the master device of FIGURE 1 and two conventional ACL slave devices. In the example of FIGURE 2, the scheduler 16 sends the first two packets to slave 1 on frequencies f_1 and f_3 of the normal frequency hopping pattern, because the channel quality to and from slave 1 is better than the channel quality to and from slave 2. Slave 1 responds on the frequencies f_2 and f_4 specified by the normal frequency hopping pattern. For the third and fourth transmissions on frequencies f_5 and f_9,

 102521-00050: 2467353.1

the scheduler of FIGURE 1 chooses to transmit to slave 2, and for the fifth and sixth transmissions on frequencies f_{11} and f_{17}, the scheduler chooses to transmit again to slave 1. As shown in FIGURE 2, both the master and the slave devices transmit on the frequencies specified by the normal frequency hopping pattern, and the master device transmits extended length packets (conventionally available in Bluetooth systems) on frequencies f_5, f_{11} and f_{17}. As mentioned above, extended packet lengths may be specified by the scheduler 16, for example, in order to take advantage of good channels and/or to accommodate larger data transmissions.

FIGURE 3 diagrammatically illustrates exemplary Bluetooth ACL communication of ACL packets between the master device of FIGURE 1 and two slave devices according to the present invention. In the example of FIGURE 3, the master transmit operation is the same as in FIGURE 2, but the slave devices slave 3 and slave 4 in FIGURE 3 deviate from the normal frequency hopping pattern to use the same frequency that was just used by the master. This permits better use of the good frequencies identified by the scheduler 16 of FIGURE 1, because these good frequencies are used in both the master-to-slave transmission and the immediately following slave-to-master transmission.

FIGURE 4 (taken together with FIGURE 1) diagrammatically illustrates pertinent portions of an exemplary embodiment of the master device of FIGURE 3. The embodiment

of FIGURE 4 includes an indicator 42 for providing to the wireless communications interface 12 of FIGURE 1 information indicative of the frequency that is to be used to receive the next slave-to-master transmission. The indicator 42 can be, for example, a register having a load input and a data input coupled to the wireless communications interface 12 of FIGURE 1. The load input of the register 42 is driven active by the wireless communications interface 12 each time the wireless communications interface completes a master-to-slave transmission to a given slave, whereupon information (received from the wireless communications interface 12) indicative of the frequency that was used for that master-to-slave transmission is loaded into the register 42 via the data input thereof. Thus, the indicator 42 indicates to the wireless communications interface 12 that the frequency that is to be used to receive the next slave-to-master transmission from a given slave is the same frequency as was used for the last transmission to that slave. The master device of FIGURE 4 can otherwise be identical to the master device of FIGURE 1.

FIGURE 5 diagrammatically illustrates pertinent portions of an exemplary embodiment of the slave devices illustrated in FIGURE 3. In the embodiment of FIGURE 5, a packet processor 53 is coupled for bidirectional communication with a communications application 55 and a wireless communications interface 51. These components can cooperate in generally conventional fashion to permit the slave device of FIGURE 5 to carry on

bidirectional wireless packet communications with the master device of FIGURE 4 via a wireless communications link 54. An indicator 56 is coupled to the wireless communications interface 51 for providing thereto information indicative of the next slave-to-master transmission frequency. The indicator 56 can be, for example, a data register having a load input and a data input driven by the wireless communications interface 51. The load input is driven active each time the wireless communications interface 51 receives a master-to-slave transmission, whereupon information (received from the wireless communications interface 51) indicative of the frequency that was used to receive that master-to-slave transmission is loaded into register 56 via the data input thereof. Thus, the indicator 56 indicates to the wireless communications interface 51 that the frequency to be used for the next slave-to-master transmission is the same as the frequency that was used to receive the most recent master transmission.

FIGURE 6 diagrammatically illustrates exemplary communications between the master device of FIGURE 1 and a slave device according to the present invention, using Bluetooth synchronous connection-oriented (SCO) links. Bluetooth SCO links reserve frequency/timeslot combinations at regular intervals for applications such as voice calls. When using SCO links, the scheduler 16 of FIGURE 1 can perform the scheduling in blocks defined by the broken lines in FIGURE 6. In the example of FIGURE 6, each block includes

six time slots, three for master-to-slave links and three for slave-to-master links. Each SCO slave will receive a packet within each block, but the time slot (and thus the frequency) selected by the scheduler for transmission to a given slave can vary from block to block. This requires the slave devices to listen to the master during all master-to-slave time slots. For a given slave, such as slave 5 in FIGURE 6, the scheduler 16 of FIGURE 1 selects the time (and thus frequency) for transmission to that slave. In the example of FIGURE 6, the frequencies f_1, f_9, f_{13} and f_{23} may be best in the respective blocks for transmission to slave 5, so the scheduler can choose to transmit to slave 5 using these frequencies. Slave 5 responds on the frequencies specified by the normal frequency hopping pattern.

FIGURE 7 diagrammatically illustrates an exemplary embodiment of the slave device illustrated in FIGURE 6. The embodiment of FIGURE 7 includes a packet processor 71 coupled for bidirectional communication with a communications application 73 and a wireless communications interface 72. These components can cooperate in generally conventional fashion to permit bidirectional wireless packet communication with the master device of FIGURE 1 via a wireless communication link 74. The embodiment of FIGURE 7 includes a MAC (media access control) processor 75 coupled to the packet processor 71 for monitoring the packets received during the master-to-slave time slots of FIGURE 6 and determining which of those packets is addressed to the slave device of FIGURE 7, and

should thus be further processed by the packet processor 71. This permits cooperation with the scheduler's ability to choose any of the three possible master-to-slave frequencies of each block in FIGURE 6 for transmission to the slave device of FIGURE 7.

FIGURE 8 diagrammatically illustrates exemplary communications between the master device of FIGURE 4 and a slave device according to the invention, using Bluetooth SCO links. In the example of FIGURE 8, the master device transmits to slave 6 in the same manner described above with respect to FIGURE 6. However, in the example of FIGURE 8, slave 6 repeats the master's frequency in generally the same manner described above with respect to FIGURE 3.

FIGURE 9 (taken together with FIGURE 7) illustrates an exemplary embodiment of the slave device illustrated in FIGURE 8. The slave device of FIGURE 9 generally combines the features of the FIGURE 7 slave device with the slave-to-master transmission frequency indicator 56 of FIGURE 5. In the FIGURE 9 slave device, the load input of the register 56 is driven active by the output 96 of AND gate 95 each time a packet addressed to the slave device (as determined by the MAC processor of FIGURE 7) is received. This arrangement permits the slave device to receive a packet on any of the three available frequencies in any of the blocks delineated by broken lines in FIGURE 8, and also to use for transmission back to the master device the frequency on which was received the most recent packet addressed

to the slave device, also as shown in FIGURE 8. The slave device of FIGURE 9 can otherwise be identical to the slave device of FIGURE 7.

FIGURE 10 diagrammatically illustrates exemplary Bluetooth SCO link communications between the master device of FIGURE 1 and three of the slave devices illustrated in FIGURE 7. As illustrated in FIGURE 10, the master device transmits to each of slaves 7-9 within each of the blocks delineated by broken lines, and the order of the transmissions to the various slaves is dictated by operation of the scheduler 16, as described in detail above. Also in this example, the master device and all of the slave devices use the transmission frequencies specified by the normal frequency hopping pattern.

FIGURE 11 illustrates exemplary Bluetooth SCO link communications between the master device of FIGURE 4 and three of the slave devices of FIGURE 9. The transmit operation of the master device illustrated in FIGURE 11 is the same as illustrated in FIGURE 10, but slaves 10-12 repeat the frequency of the most recently received packet when transmitting back to the master device.

FIGURE 12 illustrates exemplary operations which can be performed by the master devices of FIGURES 1 and 4. After obtaining frequency channel quality information at 120, a packet transmission to a given slave is scheduled at 121 based on the quality information. For Bluetooth ACL links, the scheduling can also include selecting the packet length based

on the quality information and the amount of information that needs to be transmitted to the slave. Thereafter, the packet is transmitted as scheduled at 123, after which the illustrated operations can be repeated.

FIGURE 13 diagrammatically illustrates a modified slave hopping frequency that can be utilized by the present invention, for example, in higher Doppler environments. In FIGURE 13, slave 13 transmits back to the master device on the frequency that the normal frequency hopping pattern specifies for the master device's next transmission to slave 13. Such operation advantageously permits the master device to measure the quality of the slave-to-master transmit frequency relatively soon before the master is scheduled to transmit to the slave device on that same frequency.

FIGURE 14 (taken together with FIGURE 1) diagrammatically illustrates pertinent portions of exemplary embodiments of a master device which combines the operation of the scheduler 16 of FIGURE 1 with the modified slave frequency hopping pattern illustrated in FIGURE 13. The master device of FIGURE 14 includes a scheduler 16A that is generally similar to the scheduler 16 of FIGURE 1, but also includes an override input that, for a given master-to-slave packet, causes the scheduler 16A to override the scheduling operations described above with respect to scheduler 16, and instead schedule that packet for the same frequency/time slot that would be assigned to it in the normal MS packet flow (i.e., the

frequency/time slot specified by the normal frequency hopping pattern). Thus, the scheduler 16A can produce a modified MS packet flow 22A that differs from the modified MS packet flow 22 of FIGURE 1. The override input is driven by an output 141 of a comparator 140. An input 143 of the comparator 140 receives quality information conventionally derived from a slave transmission received on a frequency on which the master device is next scheduled (by the normal frequency hopping pattern) to transmit to the slave, for example, quality information derived from slave 13's transmission on f_7 in FIGURE 13. If the comparator 140 determines that the quality associated with that frequency exceeds a predetermined threshold quality, then the comparator output 141 activates the override input of scheduler 16A. Otherwise, the override input remains inactive.

The master device of FIGURE 14 also includes an indicator 144 which provides to the wireless communications interface 12 information indicative of the frequency that will be used to receive the next slave-to-master transmission. The indicator 144 can be, for example, a register whose load input is driven active by the wireless communications interface 12 each time the wireless communications interface 12 completes a transmission to a slave device. When the load input is driven active, the register 144 is loaded via its data input with information (received from wireless communications interface 12) indicative of

the frequency specified by the normal frequency hopping pattern for the next transmission to that slave device. Thus, the register 144 indicates after each master-to-slave transmission that the next transmission from that slave is to be received on the frequency specified by the normal frequency hopping pattern for the next master transmission to that slave.

FIGURE 15 (taken together with FIGURES 7 and 9) diagrammatically illustrates pertinent portions of an exemplary embodiment of a slave device which can implement the modified slave frequency hopping pattern illustrated in FIGURE 13. The embodiment of FIGURE 15 is similar to the embodiment of FIGURE 9, with the exception that the data input of register 56 receives (from wireless communications interface 74) information indicative of the frequency specified by the normal frequency hopping pattern for receiving the next master transmission. Thus, register 56 indicates to the wireless communications interface 74 that the next slave-to-master transmission is to be performed on the frequency specified by the normal frequency hopping pattern for receiving the next master transmission.

FIGURE 16 illustrates exemplary Bluetooth SCO link communications between the master device of FIGURE 14 and the slave device of FIGURE 15. In the example of FIGURE 16, slave 14 transmits to the master device according to the modified frequency hopping pattern described above with respect to FIGURE 13, so the master device has an opportunity to make a measurement on the frequency that is specified by the normal

frequency hopping pattern for the next transmission from the master to slave 14. In the example of FIGURE 16, the quality information derived by the master device from slave 14's transmission on frequency f_7 indicates that the quality of that frequency is less than the predetermined threshold quality (see FIGURE 14), so the master device makes its next transmission to slave 14 on frequency f_9 as selected (in this example) by scheduler 16A when its override input is inactive, instead of on the frequency f_7. However, the quality information derived from slave 14's transmission on frequency f_{13} indicates that the quality of f_{13} exceeds the threshold quality, so the master's next transmission to slave 14 is on that same frequency f_{13}, as specified by the normal frequency hopping pattern (and associated with the normal MS packet flow). The slave 14 transmission on frequency f_{19} is determined to have a quality that is lower than the threshold quality, so the master's next transmission to slave 14 is on frequency f_{23} specified by the modified packet flow from scheduler 16 rather than on the frequency f_{19} specified by the normal frequency hopping pattern.

FIGURE 17 (taken together with FIGURE 12) illustrates exemplary operations which can be performed by the master device of FIGURE 14. After receiving a slave device's transmission at 171 and making a quality measurement on the received transmission at 172, it is determined at 173 whether or not the quality associated with the slave's transmission frequency exceeds a threshold quality. If so, then at 174 the frequency specified by the

normal frequency hopping pattern is used for the next transmission to the slave device, after which the next transmission from the slave device is awaited at 171. If the measured quality does not exceed the threshold quality at 173, then operations can proceed to 120 in FIGURE 12, in order to schedule and transmit the next packet to the slave device, after which operations can return from 123 in FIGURE 12 to 171 in FIGURE 17.

FIGURE 18 shows simulation results indicative of the gains that can be obtained for ACL links using the dynamic slave selection provided by the scheduler 16 of FIGURE 1. In the simulation example of FIGURE 18, retransmissions are considered and, after a packet is transmitted up to three times and is not received correctly, then the packet is considered to be lost. When the scheduler can choose between two slaves (or two frequencies), the gain in E_b/N_O is 4 dB. With a choice between three slaves, the gain is 5.5 dB, and with a choice between four slaves the gain is 6.5 dB.

FIGURE 19 shows simulation results for the gains that can be obtained for SCO links using the dynamic slave selection provided by the scheduler 16 with a block size of three master-to-slave time slots plus three slave-to-master time slots. With three simultaneous SCO links, the entire bandwidth is occupied, and the gain obtained by dynamic slave selection is 5 dB. With only two simultaneous SCO links, a gain of 12 dB can be obtained,

and with a single SCO link a gain of 14 dB can be obtained. The example of FIGURE 19 relates to HV3 (High-quality Voice) with no retransmissions.

FIGURE 20 shows simulation results for the gains that can be obtained for SCO links with the dynamic slave selection of the scheduler 16A of FIGURE 14, but operating at a higher Doppler rate than in FIGURE 19. A gain of 8 dB can be obtained, which is close to the 10 dB that could be obtained with ideal two path selection diversity.

It will be evident to workers in the art that the embodiments described above with respect to FIGURES 1-17 can be readily implemented, for example, by suitable modifications in software, hardware, or a combination of software and hardware, in conventional frequency hopping wireless communication devices, such as the above-described Bluetooth master and slave examples.

Although exemplary embodiments of the invention are described above in detail, this does not limit the scope of the invention, which can be practiced in a variety of embodiments.